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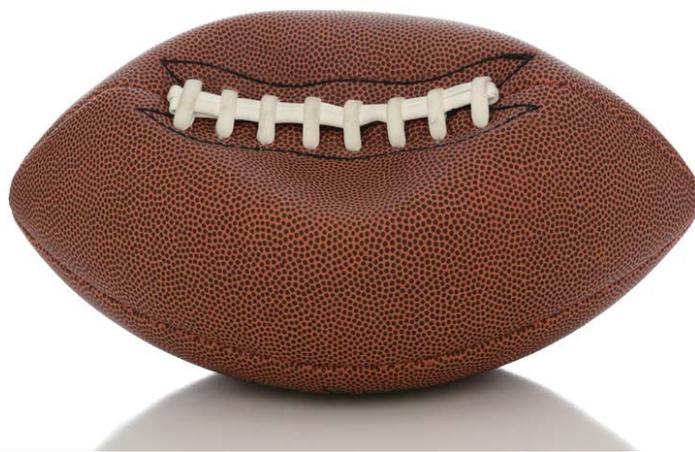
A Real Application of the Ideal Gas Law

by

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The Problem

The following information was obtained as part of an investigation by the National Football League (NFL) to determine if the New England Patriots cheated by purposefully deflating footballs during the conference title game against the Indianapolis Colts on January 18th, 2015 in Foxboro, MA. The information provided comes directly from the “Investigative Report Concerning Footballs Used During the AFC Championship Game on January 18, 2015” that was commissioned by the NFL. Your job is to analyze the data that was collected and determine if the scientific evidence suggests that the Patriots purposefully deflated footballs to gain a competitive advantage. Remember to base all of your conclusions on your analysis of the collected data.

Each team in the NFL provides 12 footballs to be used when their team is on offense. The officials check and approve the footballs before play begins. It is alleged that the Patriots tampered with the footballs after the official checked the footballs and before play began.

Summarized NFL Rules about Required Football Pressure for Footballs

1. Each team shall provide 12 footballs two and a half hours before the start of the game to be approved by officials.
2. Each football must be inflated to a pressure between 12.5 and 13.5 psi. The pressure listed is a gauge pressure, meaning that the football must be inflated 12.5 to 13.5 psi above atmospheric pressure.

Official Inspection of Footballs Before the Start of the Game

The head official inspected the footballs for both the New England Patriots and the Indianapolis Colts before the game began. The official had in his possession two different pressure gauges for checking footballs. Before the game he used one of the two gauges to measure the pressure of the footballs, but he later could not recall which gauge was used. During inspection of the footballs, the official did not take any detailed records, but he did recall that most of the Patriots’ footballs registered at 12.5 psi and that most of the Colts’ footballs measured at 13.0 psi. Some of the footballs might have been slightly off from these values, but the official could not remember the specifics. These findings are consistent with statements from both teams. The Patriots aimed to inflate their footballs to 12.5 psi and the Colts aimed to inflate their footballs to 13.0 psi. Testing of the footballs took about 25 minutes.

Start of the Game and First Half Play

Twenty minutes before the game was to begin the officials could not locate the footballs; the ball boy for the Patriots had already taken all of the footballs to the field without permission of the officials. Security footage shows that the ball boy entered a bathroom with the footballs and was inside the bathroom for one minute and forty seconds. It is alleged that the Patriots footballs were deflated while the ball boy was in the bathroom.

The evening football game was played in Foxboro, MA. The temperature at the time of kick-off was 9 °C. In the first half of the football game the Patriots quarterback threw a pass that was caught by the opposing team (Colts). The Colts player noticed that the ball seemed underinflated. The report of the Colts player led to coaches on the Colts alerting officials that the footballs the Patriots were using could be improperly inflated, violating league rules.

Halftime Analysis

During halftime the officials went to the locker room and immediately started measuring the pressure of the footballs. The temperature in a typical locker room is 22 °C. The officials measured the pressure in the Patriots footballs first. It took about four minutes to test the pressure of the Patriots game balls. The pressure of each football was measured twice. Each football was measured by both of the gauges owned by the official. Each football was measured with both gauges before the next football was measured. The results of the pressure measurements of the Patriots footballs are listed in Table 1.

Table 1: Halftime measurements of the pressure in the Patriots footballs.

<i>Patriots Ball</i>	<i>Pressure Measured with Gauge 1 (psi)</i>	<i>Pressure Measured with Gauge 2 (psi)</i>
1	11.50	11.80
2	10.85	11.20
3	11.15	11.50
4	10.70	11.00
5	11.10	11.45
6	11.60	11.95
7	11.85	12.30
8	11.10	11.55
9	10.95	11.35
10	10.50	10.90
11	10.90	11.35

The pressure of the Colts footballs was measured after the Patriots footballs were measured near the end of halftime. Due to time constraints, halftime lasts for only 13 minutes, only four of the Colts footballs were measured. The results of the pressure measurements of the Colts footballs are listed in Table 2.

Table 2: Halftime measurements of the pressure in the Colts footballs.

<i>Colts Ball</i>	<i>Pressure Measured with Gauge 1 (psi)</i>	<i>Pressure Measured with Gauge 2 (psi)</i>
1	12.35	12.70
2	12.30	12.75
3	12.95	12.50
4	12.15	12.55

Useful Information

- All pressures listed above are gauge pressures. All pressures used when applying the Ideal Gas Law should be converted to absolute pressure. Absolute pressures have a true zero. Zero absolute pressure corresponds to their being a perfect vacuum or zero molecules. To determine the absolute pressure of the footballs you need to add atmospheric pressure (14.7 psi) to the gauge pressure. For example a football that measures at 13.0 psi gauge pressure has an absolute pressure of 27.7 psi.
- All temperature used when applying the Ideal Gas Law should be converted to absolute temperature in Kelvin.
- For our purposes we can assume with little error that the volume of the football remains constant over the relevant pressure range.

Did the Patriots Cheat by Deflating Footballs?

You now have all of the relevant data that exists from the game when the Patriots were alleged to have cheated by deflating footballs. Answer the questions below and use the data to make a recommendation to the NFL regarding the alleged misconduct.

Questions

1. Will a change in temperature affect the pressure that is measured using a gauge? If so, use kinetic molecular theory to explain how pressure and temperature are related.
2. Describe quantitatively how pressure and temperature are related. This explanation should include an equation.
3. If a football is initially inflated to 12.5 psi as measured with a gauge at a temperature of 22 °C, what will the gauge pressure of the football be when the temperature is 9 °C?
4. When moved from a cold environment to a warm environment about how long will it take the temperature of the footballs to reach the temperature at which the pressure was originally measured? Use Figures 21 and 22 on pages 42 and 44, respectively, of Appendix 1 of the NFL report by Wells et al.
5. Are the two gauges calibrated such that they read the same pressure? Explain using the data in Tables 1 and 2.
6. Do the two gauges show a consistent difference? Explain using the data in Tables 1 and 2.
7. Use the data from Tables 1 and 2, your answers to the previous questions, and the Ideal Gas Law to determine if the Patriots deflated the footballs. Make sure to consider all possible scenarios, detail how you analyzed the data, and explain how you came to your conclusions.
8. We only considered the Ideal Gas Law when coming to our conclusions. What are some other factors that could affect air pressure in the footballs? How would those factors affect your analysis of the data?
9. What could the officials have done differently in collecting the data that would have helped you reach your conclusion?
10. How confident are you in your conclusions? Explain.

Reference

Wells, T.V., B.S. Karp, and L.L. Reisner. 2015. Investigative report concerning footballs used during the AFC championship game on January 18, 2015. May 6, 2015. <http://a.espncdn.com/pdf/2015/0506/PatriotsWellsReport.pdf> (accessed August 27, 2015).

All of the data and information used in the case study is from this source, which was commissioned by the National Football League.

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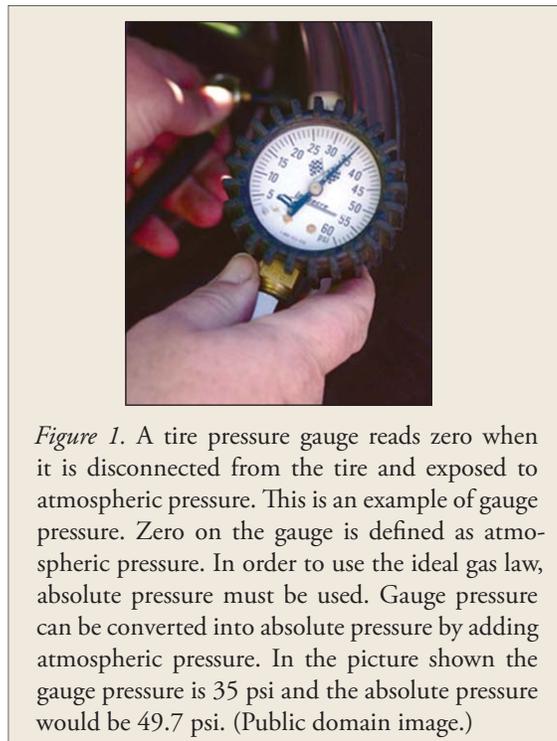


Figure 1. A tire pressure gauge reads zero when it is disconnected from the tire and exposed to atmospheric pressure. This is an example of gauge pressure. Zero on the gauge is defined as atmospheric pressure. In order to use the ideal gas law, absolute pressure must be used. Gauge pressure can be converted into absolute pressure by adding atmospheric pressure. In the picture shown the gauge pressure is 35 psi and the absolute pressure would be 49.7 psi. (Public domain image.)